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(58) Field of Search

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(54) Abstract Title

**Flow control apparatus and method**

(57) A method for obtaining equalized production from deviated wellbores comprising a plurality of spaced apart flow control device 20a-n which are deployed along the length of the wellbore 14. Each control device includes a flow valve 24a-n and control units 26a-n to control flow output from the flow control device. The control unit may communicate with surface equipment 50 or act autonomously to take actions downhole based on programmed instructions provided to the control unit. The fluid from various zones  $Z_1$ - $Z_n$  are drawn in a manner that depletes the reservoir uniformly along the entire length of the wellbore. Each flow control device is initially set at a rate determined from initial reservoir simulations or models. The depletion rate, water, oil and gas content, pressure, temperature and other desired parameters are determined over a time period. This data is utilised to update the initial reservoir model, which in turn is utilised to adjust the flow rate from one or more zones so as to equalize the flow rate from the reservoir. The present invention also provides a flow control device which includes an outer shroud (fig2B,235) that reduces the effect of fluid impact on the flow control device and one or more tortuous paths (fig2A,214) which carry the formation fluid into the production tubing (fig2A,220).

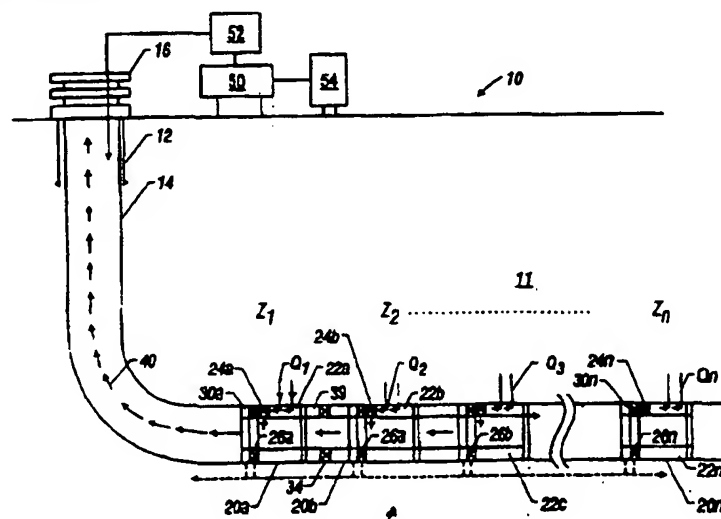


Figure 1

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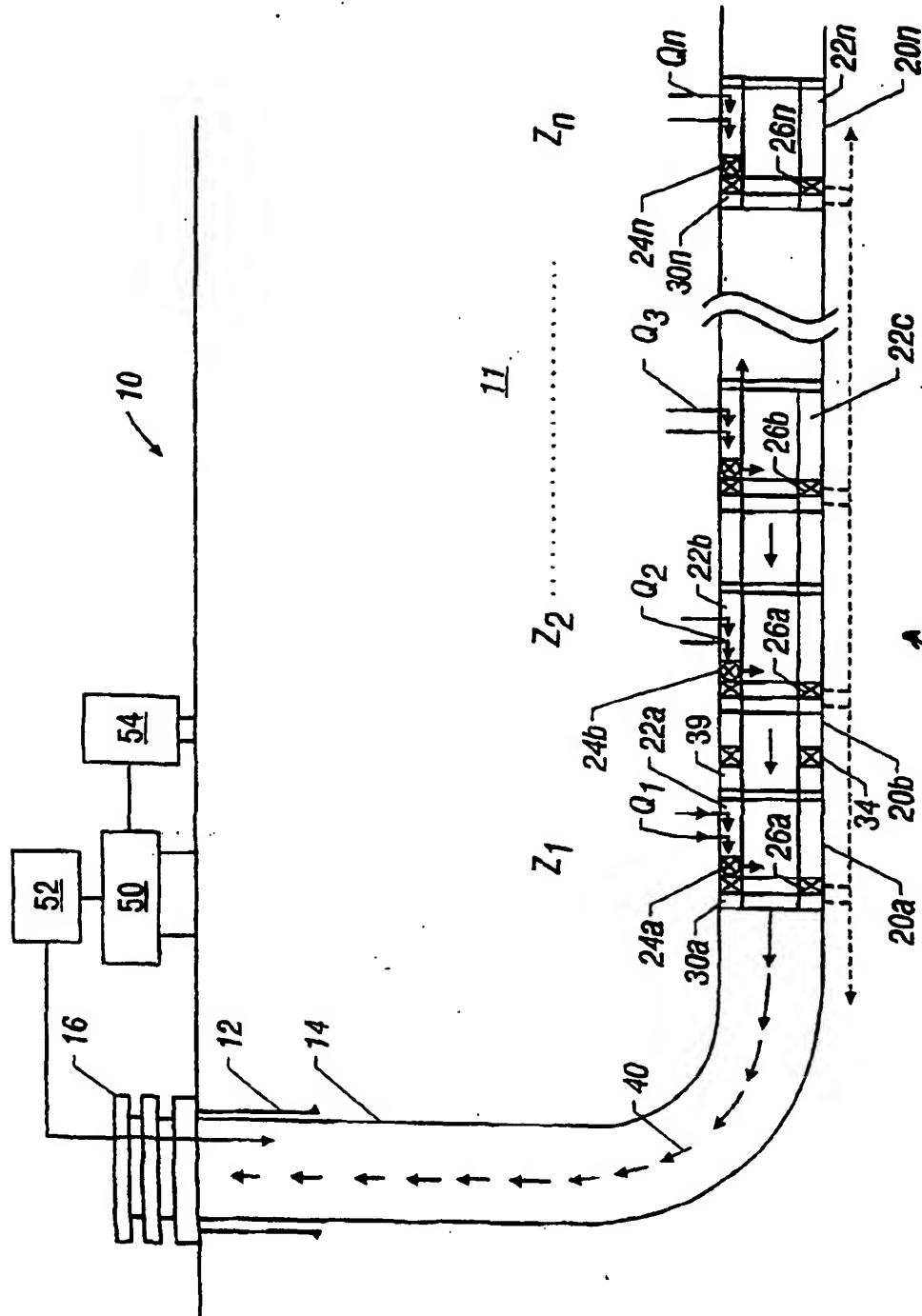


Figure 1



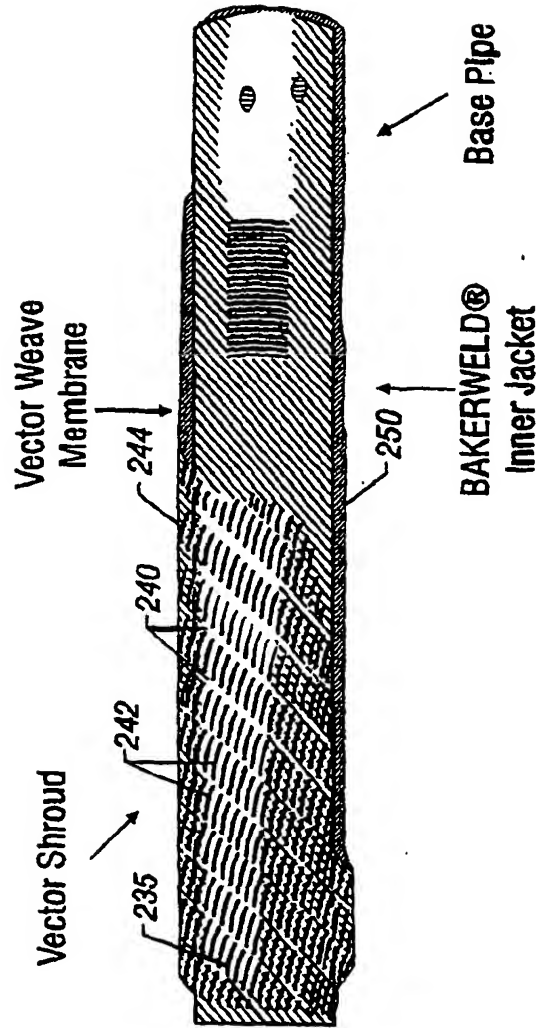


Figure 2B

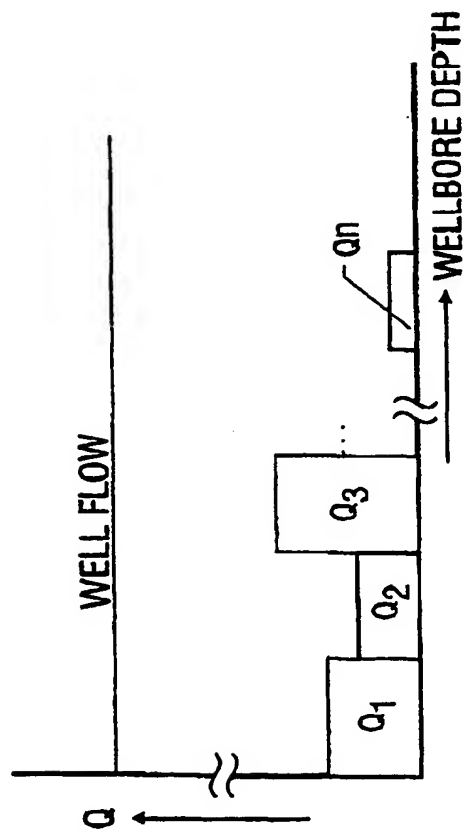


Figure 4

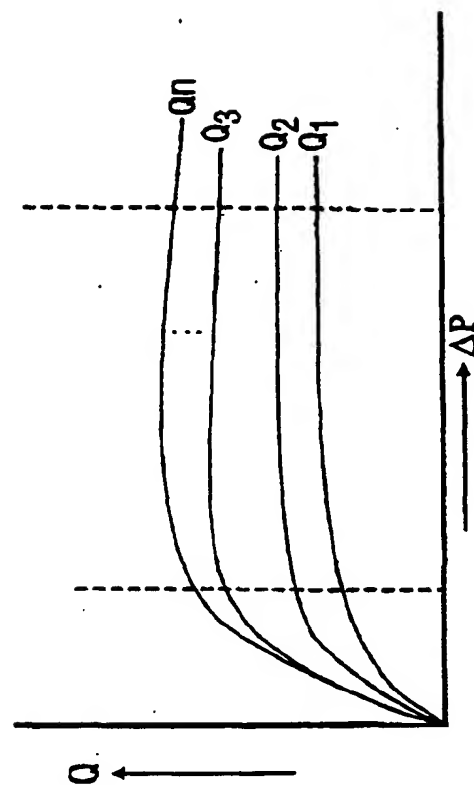


Figure 5

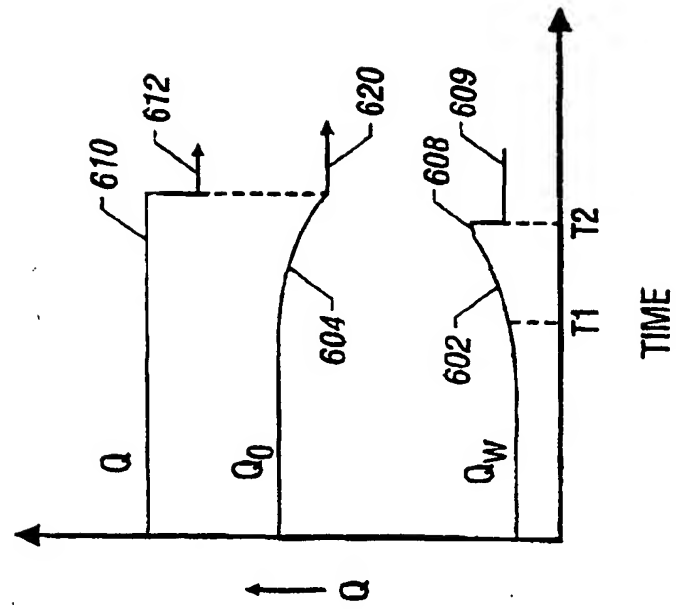
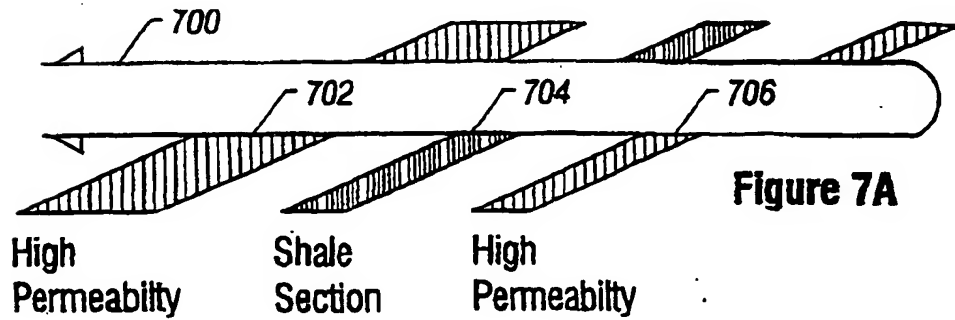
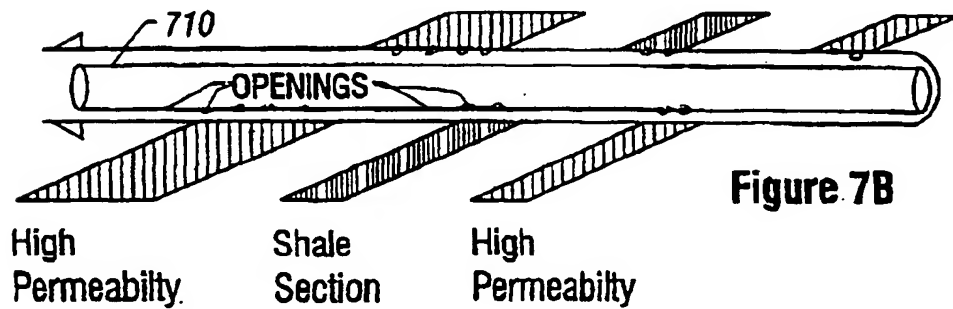


Figure 6

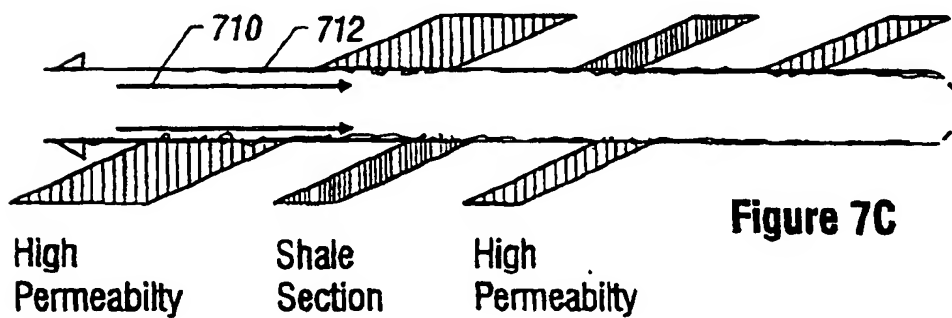
# Horizontal Well with Permeability Contrasts and Shale



The well has been drilled, logged and geophysical map has been created



Reservoir Inflow Control Device Is Run In Place



Reservoir Inflow Control Device Is Installed  
And Production Liner Can Be Run

## FLOW CONTROL APPARATUS AND METHOD

1        BACKGROUND OF THE INVENTION

2

3    1.    Field of the Invention

4

5            This invention relates generally to methods of producing hydrocarbons  
6    from wellbores formed in subsurface formations and more particularly to  
7    apparatus and methods for regulating and/or equalizing production from  
8    different zones of a wellbore to optimize the production from the associated  
9    reservoirs or pay zones.

10

11   2.    Background of the Art

12

13            To produce hydrocarbons from earth formations, wellbores are drilled  
14    into reservoirs or pay zones. Such wellbores are completed and perforated  
15    at one or more zones to recover hydrocarbons from the reservoirs.  
16    Horizontal wellbores are now frequently formed into a pay zone to increase  
17    production and to obtain on the aggregate higher quantities of the  
18    hydrocarbons from such reservoirs.

19

20            Sand screens of various designs and slotted liners are commonly  
21    placed between the formation and a tubing (production tubing) in the



1 wellbore, which transports formation fluid to the surface to prevent entry of  
2 sand and other solid particulates into the tubing. Screens of different sizes  
3 and configuration are commonly used as sand control devices. The prior art  
4 screens typically erode substantially over time. The present invention  
5 provides a screen which is less susceptible to erosion compared to prior art  
6 screens.

7

8 Excessive fluid flow rates from any production zone can cause,  
9 among other things, excessive pressure drop between the formation and the  
10 wellbore casing, relatively quick erosion of inflow devices, water or gas  
11 coning, caving, etc. Therefore, to avoid such problems, fluid flow from each  
12 production zone is controlled or regulated. Several flow control devices have  
13 been utilized for regulating or controlling production of formation fluids. One  
14 recent device passes the formation fluid through a spiral around a tubular to  
15 reduce the pressure drop before the fluid is allowed to enter the tubing. The  
16 spiral provides a tortuous path, which can be plugged at one or more places  
17 to adjust the fluid flow from the formation to the tubing. This device,  
18 although effective, must be set at the surface prior to its installation. United  
19 States Patent Application Serial No. 08/673,483 to Coon, filed on July 1,  
20 1996, and assigned to the assignee of this application, discloses an  
21 electrically operable sliding sleeve for controlling fluid flow through a

1 tortuous path. This sliding sleeve may be operated from the surface. U.S.  
2 Application No. 08/673,483 is incorporated herein by reference. The  
3 present invention provides a flow control device that can be opened, closed  
4 or set at any intermediate flow rate from the surface. It also includes  
5 multiple fluid paths, each of which may be independently controlled to  
6 control the formation-fluid flow into the tubing.

7

8 In vertical wellbores, several zones are produced simultaneously. In  
9 horizontal wellbores, the wellbore may be perforated at several zones, but  
10 is typically produced from one zone at a time. This is because the prior art  
11 methods are not designed to equalize flow from the reservoir throughout the  
12 entire wellbore. Further, the prior art methods attempt to control pressure  
13 drops and not the fluid flows from each of the zones simultaneously.

14

15 The present invention provides methods for equalizing fluid flow from  
16 multiple producing zones in a horizontal wellbore. Each production zone may  
17 be independently controlled from the surface or downhole. This invention  
18 also provides an alternative system wherein fluid flow from various zones is  
19 set at the surface based on reservoir modeling and field simulations.

20

1                                    **SUMMARY OF THE INVENTION**

2

3            The present invention provides a fluid flow control device for  
4    controlling the formation-fluid flow rate through a production string. The  
5    device includes a generally tubular body for placement into the wellbore.  
6    The tubular body is lined with a sand screen and an outer shroud. The  
7    shroud reduces the amount of fluid that directly impacts the outer surface  
8    of the screen, thereby reducing the screen erosion and increasing the screen  
9    life. The fluid from the screen flows into one or more tortuous paths. Each  
10   tortuous path has an associated flow control device, which can be activated  
11   to independently open or close each tortuous path. Alternatively, flow from  
12   each path may be regulated to a desired rate.

13

14           Each flow control device further may include a control unit for  
15   controlling the output of the flow control device. The control unit may  
16   communicate with a surface control unit, which is preferably a computer-  
17   based system. The control unit performs two-way data and signal  
18   communication with the surface unit. The control unit can be programmed  
19   to control its associated device based on command signals from the surface  
20   unit or based on programs stored in the control unit. The communication  
21   may be via any suitable data communication link including a wireline,

1 acoustic and electromagnetic telemetry system. Each flow control device  
2 may be independently controlled without interrupting the fluid flow through  
3 the production string. The flow control devices may communicate with each  
4 other and control the fluid flow based on instructions programmed in their  
5 respective control units and/or based on command signals provided from the  
6 surface control unit.

7

8 In a preferred method, a plurality of spaced apart flow control device  
9 are deployed along the length of the horizontal wellbore. In one method of  
10 the invention, it is preferred to draw fluids from various zones in a manner  
11 that will deplete the reservoir uniformly along the entire length of the  
12 wellbore. To achieve uniform depletion, each flow control device is initially  
13 set at a rate determined from initial reservoir simulations or models. The  
14 depletion rate, water, oil and gas content, pressure, temperature and other  
15 desired parameters are determined over a time period. This data is utilized  
16 to update the initial reservoir model, which in turn is utilized to adjust the  
17 flow rate from one or more zones so as to equalize the flow rate from the  
18 reservoir.

19

20 In an alternative method, production zones are defined and flow  
21 setting for each zone is fixed at the surface prior to installation of the flow

1 control devices. Such a system is relatively inexpensive but would only  
2 partially equalize the production from the reservoir as it would be based on  
3 *a priori* reservoir knowledge.

4  
5 The present invention provides a method of producing hydrocarbons  
6 from a reservoir having a deviated/substantially horizontal wellbore formed  
7 therein, said method, comprising: (a) placing a plurality of flow control  
8 devices in the wellbore, each flow control device set to produce formation  
9 fluid at an initial rate associated with each such flow control device; (b)  
10 determining at least one characteristic of the fluid produced through the  
11 wellbore; and (c) adjusting the flow rate through said flow control devices  
12 so as to equalize depletion of hydrocarbons from the reservoir over a time  
13 period.

14  
15 Examples of the more important features of the invention have been  
16 summarized rather broadly in order that the detailed description thereof that  
17 follows may be better understood, and in order that the contributions to the  
18 art may be appreciated. There are, of course, additional features of the  
19 invention that will be described hereinafter and which will form the subject  
20 of the claims appended hereto.

21

**BRIEF DESCRIPTION OF THE DRAWINGS**

For detailed understanding of the present invention, reference should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals, and wherein:

FIG. 1 shows a horizontal wellbore having a plurality of spaced apart flow control devices for producing hydrocarbons from a reservoir according to one method of the present invention.

FIG. 2A shows a partial schematic view of a flow control device for use in the system shown in FIG. 1.

FIG. 2B shows a partial cut off view of a sand control section for use with the flow control device of FIG. 2A.

FIG. 3 shows control devices and certain sensors for use with the flow control device of FIG 2A.

FIG. 4 shows a hypothetical graph showing the flow rate from various

1 zones of a horizontal wellbore according to one method of the present  
2 invention.

3

4 FIG. 5 shows a relationship between the pressure differential and the  
5 flow rate associated with various production zones of a wellbore.

6

7 FIG. 6 shows a scenario relating to the effect of adjusting the flow  
8 rate from a production zone on production of hydrocarbons and water from  
9 such zone.

10

11 FIG. 7 shows an alternative method of equalizing production from a  
12 reservoir by a horizontal wellbore to the method of system of FIG. 1

13

#### 14 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

15

16 FIG. 1 is a schematic illustrating a system 10 for producing  
17 hydrocarbons from a wellbore according to one method of the present  
18 invention. FIG. 1 shows a wellbore 14 having an upper casing 12 formed in  
19 an earth formation 11 according to any known method. A plurality of fluid  
20 flow devices or fluid flow devices 20a-n are placed spaced apart in the  
21 horizontal segment 14a of the wellbore 14. For the purposes of this

1 disclosure, a flow control device is generally designated by numeral 20. The  
2 construction and operation of a novel flow control device for use as the flow  
3 control devices 20 are described below in reference to FIGS 2A-B. However,  
4 for the purpose of this invention, any suitable flow control device may also  
5 be used. The spacings between the flow control devices 20 are determined  
6 based on the characteristics of the reservoir 11, as described in more detail  
7 later.

8  
9 Each flow control device 20a-n includes a flow valve and a control  
10 unit. The devices 20a-n are respectively shown to contain flow regulation  
11 devices such as valves, valves 24a-n and control units 26a-n. For the  
12 purposes of this invention, a flow control device is generally designated by  
13 numeral 24 and a control unit is generally designated by numeral 26. Also,  
14 for the purpose of this invention, flow control valves 24 shall mean to  
15 include any device that is utilized to control the flow of fluid from the  
16 reservoir 11 into the wellbore 14 and control units 26 shall mean to include  
17 any circuit or device that controls the flow valves 24.

18 When the wellbore is in production phase, fluid 40 flows from the  
19 formation 11 into channels 22a - 22n at each flow control device, as shown  
20 by the arrow 22a'-22n'. The flow rate through any flow control devices 20  
21 will depend upon the setting of its associated flow control valve 24. For the



1 purpose of illustration, the flow rates associated with the flow control  
2 devices 20a-20n are respectively designated by  $Q_1-Q_n$  corresponding to  
3 production zones  $Z_1-Z_n$  of the formation 11.

4 Still referring to FIG. 1, each flow control device 20a-20n or zone  $Z_1-$   
5  $Z_n$  may have any number of devices and sensors for determining selected  
6 formation and wellbore parameters. Elements 30a-30n respectively  
7 represent such devices and sensors corresponding to flow control devices  
8 20a-20n or zones  $Z_1-Z_n$ . Such devices and sensors are generally designated  
9 by numeral 30. Devices and sensors 30 preferably include temperature  
10 sensors, pressure sensors, differential pressure sensors for providing the  
11 pressure drop between selected locations corresponding to the production  
12 zones  $Z_1-Z_n$ , flow rate devices, and devices for determining the constituents  
13 (oil, gas and water) of the formation fluid 40. Packers 34 may be  
14 selectively placed in the wellbore 14 to prevent the passage of the fluids  
15 through the annulus 39 between adjacent sections.

16

17 The control units 26a-26n control the operation of their associated  
18 flow control valves 24a-24n. Each control unit 26 preferably includes  
19 programmable devices, such as microprocessors, memory devices and other  
20 circuits for controlling the operation of the flow control devices 20 and for  
21 communicating with other sensors and devices 30. The control units 26

1 also may be adapted to receive signals and data from the devices and  
2 sensors 30 and to process such information to determine the downhole  
3 conditions and parameters of interest. The control units 26 can be  
4 programmed to operate their corresponding flow control devices 20 based  
5 upon stored programs or commands provided from an external unit. They  
6 preferably have a two way communication with a surface control system 50.  
7 The surface control system 50 preferably is a computer-based system and  
8 is coupled to a display and monitor 52 and other peripherals, generally  
9 referred to by numeral 54, which may include a recorder, alarms, satellite  
10 communication units, etc.

11

12 Prior to drilling any wellbore, such as the wellbore 12, seismic surveys  
13 are made to map the subsurface formations, such as the formation 11. If  
14 other wellbores have been drilled in the same field, well data would exist for  
15 the field 11. All such information is preferably utilized to simulate the  
16 condition of the reservoir 11 surrounding the wellbore 14. The reservoir  
17 simulation or model is then utilized to determine the location of each flow  
18 control device 20 in the wellbore 14 and the initial flow rates  $Q_1-Q_n$ . The  
19 flow control devices 20a-20n are preferably set at the surface to produce  
20 formation fluids therethrough at such initial flow rates. The flow control  
21 devices 20a-20n are then installed at their selected locations in the wellbore

1 14 by any suitable method known in the art.

2

3 The production from each flow control device 20  
4 initial equilibrium. The data from the devices 30a-30  
5 determine the fluid constituents, pressure drops, and  
6 parameters. Based on the results of the computed param  
7 starting reservoir model is updated. The updated mode  
8 determine the desired flow rates for each of the zon  
9 substantially equalize the production from the reservoir  
10 through each of the flow control devices 20a-20n is t  
11 adjusted so as to uniformly deplete the reservoir. For exa  
12 zone starts to produce water at more than a preset valu  
13 device associated with such zone is activated to reduce t  
14 such zone. The fluid production from any zone producing  
15 be completely turned off. This method allows manipula  
16 from the reservoir so as to retrieve the most amount of  
17 a given reservoir. Typically, the flow rate from eac  
18 decreases over time. The system of the present inventio  
19 to independently and remotely adjust the flow of fluid  
20 producing zones, without shutting down production.

21